

Comparison of Performance Characteristics of NG and Gasoline - Fuelled Single Cylinder SI Engine

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Abstract— The Compressed Natural Gas (CNG) is a vaporous type of regular gas, it has been proposed as one of the promising option fuel because of its considerable advantages contrasted with gas and diesel. Iraq is considered as the fundamental NG repositories on the planet. Albeit normal gas can meet strict motor discharge controls in numerous nations, it has not utilized as a fuel for transport motors.

In this study, regular gas motor qualities were explored tentatively to assess the impact of motor rate and torques on the execution of SI motor energized with NG. The outcomes were contrasted with the motor when it was energized with Iraqi routine gas. The outcomes demonstrate that HUCR for Iraqi ordinary fuel was 8:1, and it was 14.0:1 for NG. Fuel's brake power (bp) is the most elevated brake powers among the tried cases, when the motor worked at gas HUCR=8:1. Utilizing NG diminished brake specific fuel consumption (bsfc) when the motor was worked at its HUCR, while at CR=8:1 it got to be higher. Gas has the least bsfc. Volumetric effectiveness decreased by utilizing NG because of its vaporous nature; however, it was generally enhanced when the motor was keep running at HUCR. Fumes gas temperatures diminished by utilizing NG, because of its low blazing speed and its low warming worth. The outcomes illuminate that utilizing NG to fuel a car motor requests expanding motor pressure proportion to accomplish the utilized NG HUCR.

Index Terms— *Natural gas; performance; brake power; brake specific fuel consumption; brake thermal efficiency; volumetric efficiency*

I. INTRODUCTION

It is well known that fossil fuel reserves all over the world are diminishing at an alarming rate and a shortage of crude oil is expected at the early decades of this century. It is believed that crude oil and petroleum products will become very scare and costly to find and produce. Gasoline and diesel will

become scarce and most costly [3].

Natural gas as an alternative fuel has been studied in several researches to substitute fossil fuel oil. Its accessibility and use should and will turn out to be more normal in the coming decades. Common gas is found in different areas in oil and gas bearing sand strata situated at different profundities beneath the earth surface [14]. The common gas is more often than not under significant weight and streams out actually from the oil well.

Iraq is considered as one of the main reserves in the world [8]. Till today there are many findings which increase Iraq reserves. Fig. 1 shows the Iraqi natural gas reserves with years [8]. Unfortunately, till today the usage of natural gas in Iraq is very limited. Iraqi government decided in 2013 to use NG as a fuel for automotive with gasoline. This step demands more interesting in studying this gas specifications and its characteristics in spark ignition engine [1].

Extensive Research has given a way for using NG as an alternate fuel in many countries. Utilization of characteristic gas for powering the motors lessens receptive hydrocarbons and don't represent the issue of vaporization as with the fluid fills [11]. Mixes, for example, 0-4% Nitrogen, 4% ethane and 1-2% propane Methane has a lower carbon to hydrogen proportion in respect to gas, so its CO₂ outflows are around 22-25% lower than gas [4]. Common gas is put away in a compacted (CNG) state at room temperatures furthermore in a fluid structure (LNG) at (- 160oC). Due its high auto start temperature it has an exploration octane number (RON) of around 127, which is suited for SI motors. The motor can be keep running on without thumping on high pressure proportions. Table 1 portrays the vital properties of CNG, gas and diesel fuel [15].

Most existing packed normal gas vehicles use petrol motors, adjusted by post-retail retrofit changes and hold bi-fuel capacity. Bi-fuelled vehicle changes by and large experience the ill effects of a force misfortune and can experience drivability issues, because of the outline and/or establishment of the

Retrofit bundles [2]. Single-fuel vehicles streamlined for packed characteristic gas are prone to be impressively more appealing as far as execution and to some degree more alluring as far as expense. As per Chaichan [5] that a characteristic gas-controlled, single-fuel vehicle ought to be fit for comparative force, comparable or higher effectiveness and for the most part lower discharges than an equal petrol-fuelled vehicle. Such a vehicle would have a much shorter driving extent unless the fuel tanks are made expansive, which would then involve a further punishment in weight, space, execution and expense.

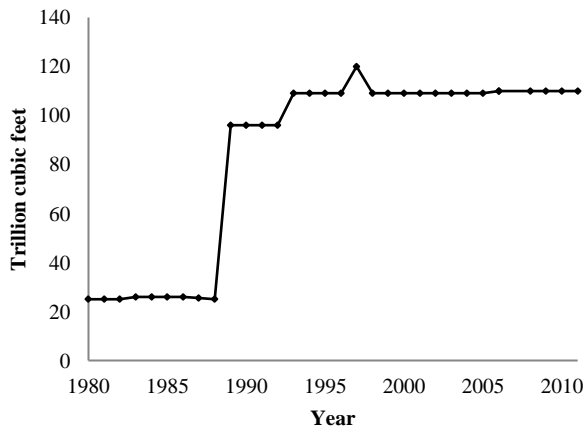


Fig. 1: Iraqi natural reserves by year [8]

Table 1: CNG properties [4]

CNG properties	Value
Density (kg/m ³)	0.72
Flammability limits (volume % in air)	4.3-15
Flammability limits (Ø)	0.4-1.6
Autoignition temperature in air (°C)	723
Minimum ignition energy (mJ)	0.28
Flame velocity (m/sec)	0.38
Adiabatic flame temperature (°C)	1941
Quenching distance (mm)	2.1
Stoichiometric fuel/air mass ratio	0.069
Stoichiometric volume fraction	% 9.48
Lower heating value (MJ/kg)	45.8
Heat of combustion (MJ/kg)	2.9

The aim of this article is to evaluate the performance of SI engine fueled with NG and the effect of engine speed and torques on it. This work is

CNG vehicles' extent constraints, be that as it may, would be facilitated impressively if LNG were substituted as the fuel [13]. The CNG fuel properties and characteristics are given in Tables 1 and 2.

Packed Natural Gas (CNG) is appealing for five reasons. It is the main fuel less expensive than gas or diesel [18]. It has characteristically brought down air contamination emanations [2]. It has lower nursery gas emanations [9]. Its utilization broadens petroleum supplies and there are vast amounts of the fuel accessible on the planet [12].

Table 2: CNG green fuel characteristics [18]

CNG Characteristics	Value
Vapor density	0.68
Auto Ignition	700°C
Octane rating	130
Boiling point (Atm. Press)	-162°C
Air-fuel ratio (weight)	17.24
Chemical reaction with rubber	No
Storage pressure	20.6 MPa
Fuel Air Mixture Quality	Good
Pollution CO-HC-NOx	Very low
Flame speed m sec ⁻¹	0.63
Combustibility with air	4-14%

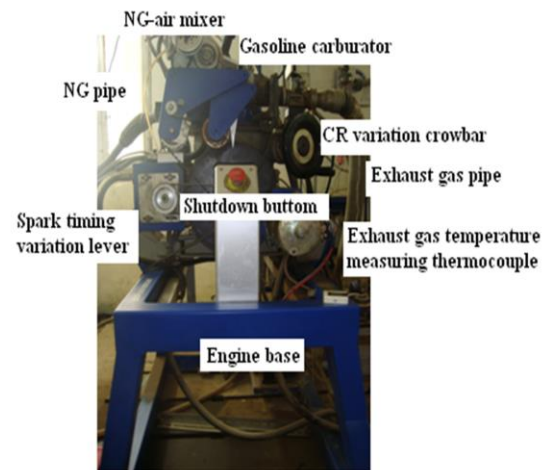


Fig. 2, Single cylinder Prodit spark

a part of the efforts of UOT, Iraq to increase the awareness in green energy usage [19-72].

II. EXPERIMENTAL SETUP

A. The engine and associates

Internal combustion engine and its accessories is shown in Fig. 2. The motor utilized as a part of this examination was 4 stroke single chamber SI motor, with variable pressure proportion, spark timing, a/f proportion and speed sort Prodit, the motor is associated with water powered dynamo-meter.

Fig. 2 shows a photographic picture of the used engine, while Fig. 3 represents a schematic diagram of the used system, while table 3 illustrates the used engine specifications.

Fuel supply framework: This framework comprises of real tank (6 liter limit), minor tank (1liter limit), and gas carburetor. This carburetor is a mechanical controlled variable deflection carburetor with cylinder sort throttle was chosen. The throttle is arranged in the endeavor zone itself, region of the endeavor was changed by throttling carburetor cylinder all over to give the right amount of blend to meet the motor working conditions. The amount of fuel conveyed was controlled by planes and sections and metering needle moving inside the aligned openings.

NG supply systems: This system consists of NG cylinder, pressure regulator, fuel drier, solenoid valve, NG adapter, gaseous fuel flow measuring device (orifice plate), damping box.

B. Control Devices

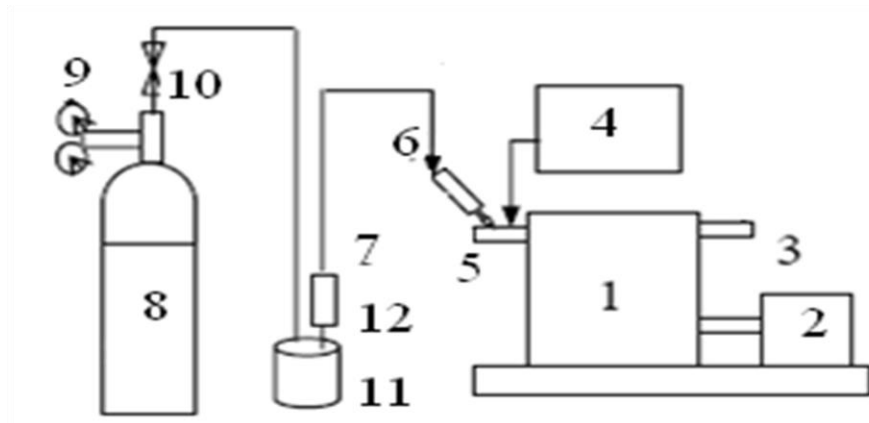
Wind current estimation: Air entering the motor was measured by "Alock" gooey stream meter associated with fire trap. The weight contrast on both sides of this gadget was measured by slanted manometer utilizing the condition:

$$m_a^o = 3.497 \times 10^{-4} \times H_a \times T_a^{-1} \times (P_a - 0.3676 H_a)$$

Speed estimation: Engine pace was measured by simple tachometer sort (VDO) with pace range from 0 to 3500 rpm.

Power estimation: The pressure driven dynamometer was utilized to quantify the brake torque of the motor by utilizing grinding liquid. Water was utilized as the rubbing liquid. This dynamometer was utilized to quantify demonstrated force, brake mean viable weight and contact lost force.

Fumes gas temperatures measurement: Exhaust gas temperatures were measured by thermocouple sort K, which was adjusted before it was utilized. The thermocouple was connected to advanced thermometer sort Masashotu 2146 (made in Japan) with perusing range from - 50 to 800 °C and precision of $\pm 2^\circ\text{C}$.



- | | |
|-----------------------------|--|
| 1. Single cylinder engine | 8. natural gas cylinder |
| 2. Dynamometer | 9. Pressure gauge and pressure regulator |
| 3. Engine exhausts manifold | 10. Non return valve |
| 4. Air drum | 11. Flame trap |
| 5. Engine intake manifold | 12. Orifice plate system |
| 6. Gas carburetor | |
| 7. Solenoid valve | |

Fig. 3, schematic diagram of the engine test rig.

A simple, low cost air-NG mixing device, designed as shown in Fig. 4, was used to mix NG with inlet air during suction stroke.

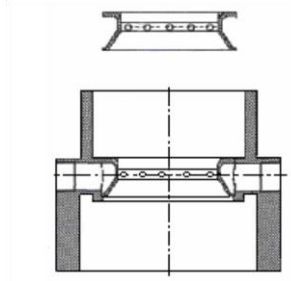


Fig. 4, the cross sectional drawing of the mixer

Start timing was balanced for every motor speed and load for better motor execution and efficiency. To make up for fuel and NG application, start timing was improved to accomplish better power, torque and execution. Variable start timing of 15° BTDC at low sitting motor pace to 25° BTDC at evaluated motor velocity was streamlined for fuel mode and 29° BTDC at appraised pace was upgraded for NG mode.

Since NG operation was in open circle, streamlining of fuel stream has been enhanced on max torque indicate all together get ideal working lambda and best power which has additionally empower dependability out of gear operation of the motor. Motor parameters were additionally recorded for brake power (bp), brake particular fuel utilization (bsfc) and fumes gas temperatures with various start timing to accomplish best fuel utilization. Motor full throttle execution in NG was observed to be superior to anything variable throttle. Lambda was kept up between 1.05-1.0 through full load exhibitions.

Table 3: Engines pacifications

Manufacturer	PRODIT	No load speed range (rpm)	500 to 3600 (Otto cycle)
Cycle	OTTO or DIESEL, four strokes	Load speed range (rpm)	1200 to 3600 (Otto cycle)
Number of cylinder	1 vertical	Intake star	54° BTDC
Diameter (mm)	90	Intake end	22° ATDC
Stroke (mm)	85	Exhaust start	22° BTDC
Compression ratio	4 to 17.5	Exhaust end	54° ATDC
Max .power	4kWatt 2800 rpm	Fixed spark advance	10° (spark ignition)
Max .torque	28 Nm at 1600 rpm	Swept volume (cm ³)	541

C. Types of fuel used

In this work the gas utilized was Iraqi customary Dora refinery creation with octane No. 82. Iraqi fuel is described by its low octane number and high lead AND sulfur content. The NG fuel created from Al-Taji Gas Company; comprises of ethane 0.8%, 0.47% iso-butane, 9.8% propane and 0.045% helium, 0.3 N₂ and 88.58% methane. By and by, a significant part of the vaporious energizes accessible are normally blends of different powers and a few diluents, constituents that can fluctuate broadly in nature and fixation, contingent upon the kind of fuel and its starting point.

Gasoline fuel flows from 20 liter tank to scale beaker with two scales 100 ml and 200 ml. The time requires the engine to consume any of the scales was measured and m_f^o was evaluated and recorded.

Natural gas was flowed from a cylindrical container with high pressure through pressure regulator with two gauges one shows the cylinder inner pressure, while the second shows the delivered pressure. This regulator has a control cock to control the pressure of the delivered gas. Non return valve type XDE 2000 was used in addition to a flame trap type Glasson Italy made to prevent backfire hazards if any. NG was being passed through orifice plate where the pressure difference between its two edges was measured by means of water manometer and the NG flow rate was calculated by the equation:

$$m_f^o = 7.23163 \times 10^{-5} \sqrt{\rho_f \times h_f}$$

NG passed through gas carburetor (after being mixed with air) directly to engine.

D. Data Reduction

The fundamental equations describing the performance of spark ignition engine are:

- The brake power (bp):

$$(1)bp = \frac{w_b \times N}{348.067}$$

where:

w_b - the load in (N)

N - speed engine (rpm)

- The brake specific fuel consumption (bsfc):

$$(2)bsfc = \frac{m_f^o \times 3600}{bp}$$

where

m_f^o - fuel consumption mean (kg/kW h)

- The volumetric efficiency:

$$\eta_{vol} = (m_a)_{act} / (m_a)_{theo} \quad (3)$$

where: theoretical air mass flow rate

$$\dot{m}_{a,theo} = V_{s,n} \times \frac{N}{60 \times 2} \times \rho_{air} \quad \frac{kg}{sec}$$

- The brake thermal efficiency:

$$(4)\eta_{bth} = \frac{bp}{m_f^o \times (LCV)}$$

where:

LCV- lower heating value = 43700 (kJ/kg) for gasoline

- The equivalent ratio (ϕ) is defined as:

$$\phi = (A/F)_{stoichiometric} / (A/F)_{actual} \quad (5)$$

The wide differing qualities in the structure of the vaporous powers generally accessible and their similarly wide assortment of their related physical, concoction and burning attributes make the expectation and advancement of their ignition conduct in motors a more considerable undertaking contrasted with ordinary fluid powers.

E. Test procedure

The main tests set were directed to decide the higher helpful pressure proportion for every fuel. Motor execution was tried for extensive variety of paces, full load conditions, ideal sparkle timing and 1500 rpm motor rate. The experiments were conducted on the engine with gasoline and engine performance was evaluated:

1-When the torque is constant at (10 Nm) and engine speed was varied (1000, 1500, 1750, 2000, 2250 and 2500 rpm).

2-When engine speed was fixed at (1500 rpm) and engine torque was changed (10, 15, 20 and 25 Nm).

The second tests set were conducted on the engine fueled with NG fuel, and engine performance was evaluated and compared with the first case.

III. RESULTS AND DISCUSSION

A. Engine Speed Effect

The performance and emissions of gas engines depends on good ignition, optimum combustion rate, high knock resistance, and a sufficient energy content of the fuel mixture.

Figures 5 and 6 speak to motor brake power came about by filling it with fuel and NG at stoichiometric identicalness proportion, variable pressure proportions, full load conditions, ideal flash planning and 1500 rpm motor pace.

Brake power increased with the increase of engine speed. The HUCR for gasoline was 8:1 as fig. 5 declares and 14.0:1 for NG as fig. 6 manifests. Any CR increment above these limits caused high engine knock. NG has higher octane number compared to gasoline which means higher knock resistance. In the following figures NG at CR=8:1 which is HUCR for Iraqi conventional gasoline and NG at HUCR=14:1 will be compared with gasoline at its HUCR= 8:1.

Fig. 7 represents the variations in bp at variable engine speeds. NG at CR=8:1 produced the lowest bp compared to the other conditions. NG at its HUCR produced bp relatively lower than gasoline, and its bp goes down at high engine speeds. NG entered the combustion chamber in gaseous phase reducing volumetric efficiency which resulted in reducing bp at high speeds.

BSFC for NG at its HUCR or at CR=8:1 is higher than that for gasoline, as Fig. 8 manifests. At CR=14:1 combustion chamber pressure and temperatures were high, but due to lower heating values of NG, the cooperation of these two parameters resulted in the bsfc for NG at its HUCR to be near that for gasoline. At CR= 8:1 another parameter interfered in increasing bsfc of NG, it was the low burning velocity of NG compared with gasoline although OST was used in these experiments.

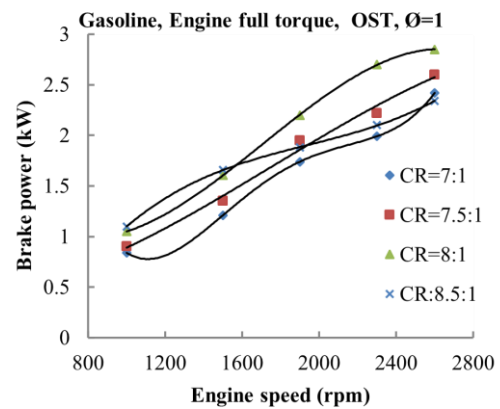


Fig. 5, CR effect on bp at variable engine speed for gasoline

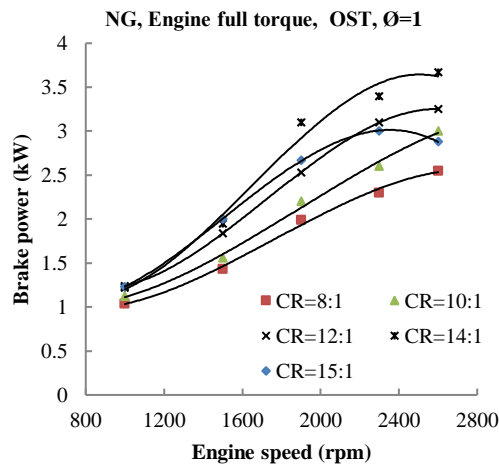


Fig. 6, CR effect on bp at variable engine speed for NG

Figures 5 and 6 speak to motor brake power came about by filling it with fuel and NG at stoichiometric equivalence proportion, variable pressure proportions, full load conditions, ideal spark timing and 1500 rpm motor velocity. Due to the gaseous phase of NG entering combustion chamber, its volumetric efficiency reduced compared to gasoline. Gasoline evaporates at carburetor absorbing heat of evaporation from surrounding air, reducing air temperature and increasing its density causing higher volumetric efficiency as Ref [7] manifests.

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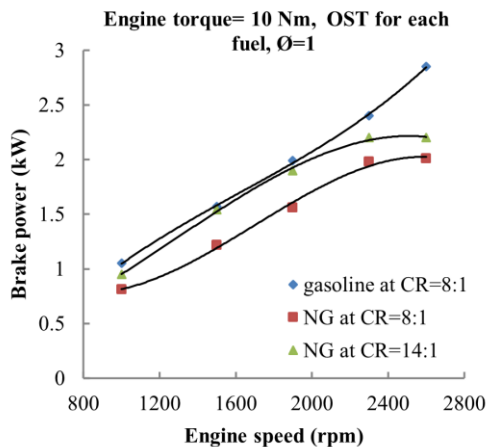


Fig. 7, Comparison of bp for gasoline and NG at variable speed

BSFC for NG at its HUCR or at CR=8:1 is higher than that for gasoline, as Fig. 8 manifests. At CR=14:1 combustion chamber pressure and temperatures were high, but due to lower heating values of NG, the cooperation of these two parameters resulted in the bsfc for NG at its HUCR to be near that for gasoline. At CR= 8:1 another parameter interfered in increasing bsfc of NG, it was the low burning velocity of NG compared with gasoline although OST was used in these experiments.

Fig. 9 demonstrates the relationship between motor rate and volumetric productivity for the utilized fills. Amid motor operation there was drop in volumetric proficiency watched, drop in volumetric effectiveness was generally because of poor NG fuel and throb impact at higher motor velocity.

Increasing CR improved NG volumetric efficiency and bring it close to gasoline one except at high engine speed where the two efficiencies converge.

Fig. 10 represents the effect of engine speed on brake thermal efficiencies for the studied cases. Brake thermal efficiency depends on bsfc, when it reduced brake thermal efficiency increases. NG bsfc was higher than that for gasoline.

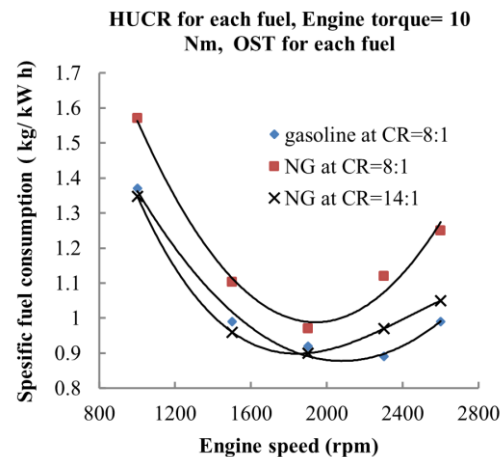


Fig. 8, Comparison of bsfc for gasoline and NG at variable speed

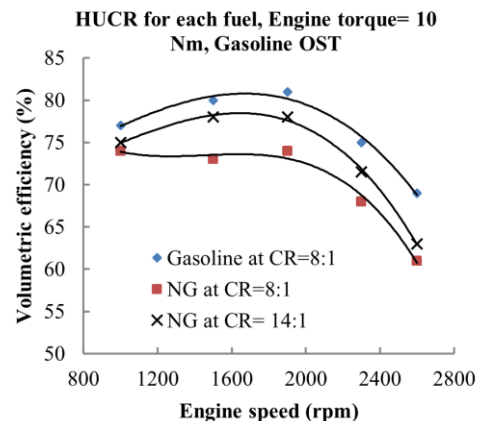


Fig. 9, Comparison of volumetric efficiency for gasoline and NG at variable speed

This is why brake thermal efficiency with using NG at its HUCR was near that for gasoline. While at HUCR for gasoline

Fig. 11 illustrates the effect of engine speed variation on exhaust gas temperatures for the studied cases. Gasoline produced the higher exhaust gas temperatures taking advantages of its higher heating value.

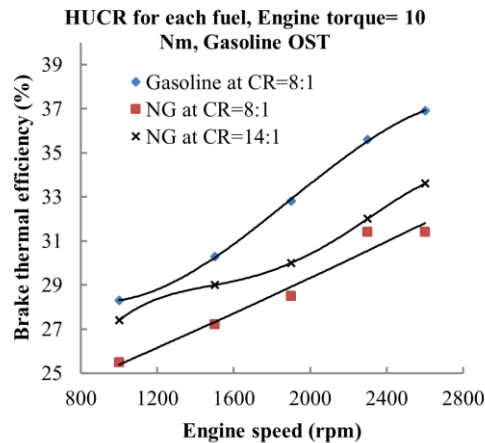


Fig. 10, Comparison of brake thermal efficiency for gasoline and NG at variable speed

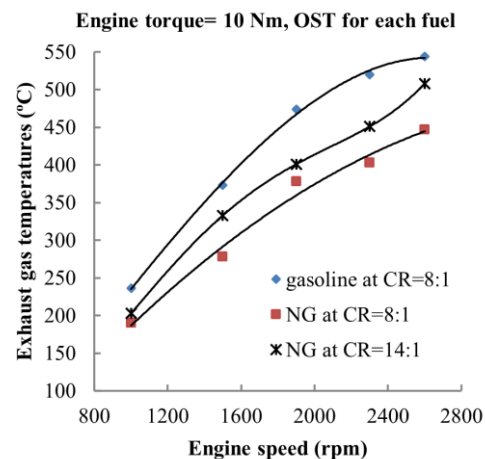


Fig. 11, Comparison of exhaust gas temperatures for gasoline and NG at variable speed

NG at CR=14:1 produced exhaust gas temperatures close to those produced by gasoline but still less than it due to its lower heating value. At CR=8:1 many parameters operated against NG, like low volumetric efficiency, low burning velocity and lower pressure and temperature inside combustion chamber.

B. Engine Torque Effect

Fig 12 shows the effect of engine torque variation on bp for the studied cases. To meet most extreme braking torque

motor needs to accomplish top ignition weight which is conceivable on the off chance that it's optimal blaze term is accomplished. With development in start timing perfect smolder span of fuel blend builds which enhances motor torque. Increasing load increased bp more for both gasoline and NG. Also, increasing torque increased combustion chamber temperatures which improved fuels burning and engine performance. While working at CR=8:1 reduced bp resulted from NG compared with gasoline. The optimum presentation of NG engines is by increasing its compression ratio to HUCR for it.

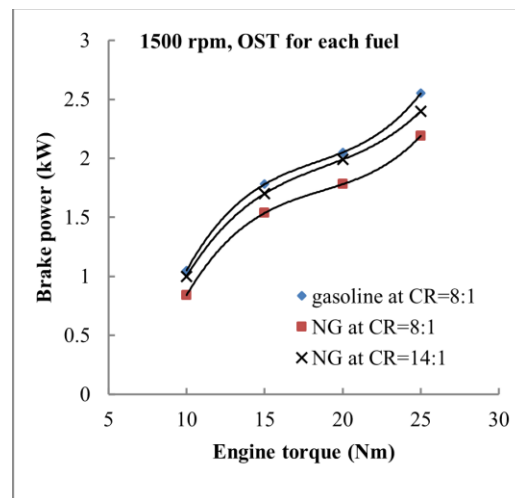


Fig. 12, Comparison of bp for gasoline and NG at variable torques

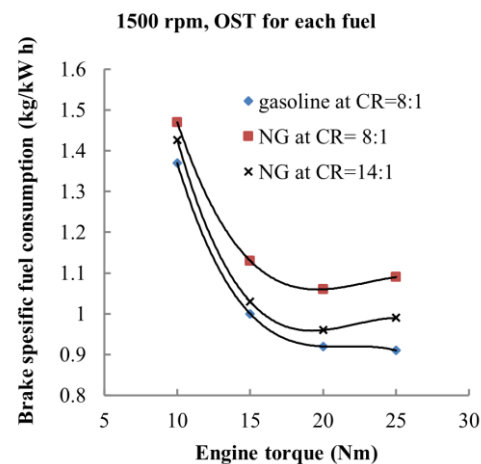


Fig. 13, CR effect on bsfc at variable engine speed for NG

Fig. 13 represents engine torque variation effect on bsfc for the studied cases. BSFC for gasoline was less than that of NG at all torques. Operating the engine at HUCR for NG resulted in high bp and the less bsfc, which means the optimum operation.

Fig. 14 demonstrates that volumetric efficiencies for NG at its HUCR improved at medium torques and descends slightly at high torques compared with gasoline. Operating NG engine at any compression ratio less than HUCR will cause losses in bp, bsfc and lower volumetric efficiency as the former figures clarify.

Fig. 15 demonstrates that NG at its HUCR resulted in high brake thermal efficiencies at medium torques but still less than that resulted by gasoline.

At low torques the combustion chamber temperature is low add to NG low burning velocity, and at high torques more NG (with its gaseous phase) must be entered to combustion chamber to preserve the required speed.

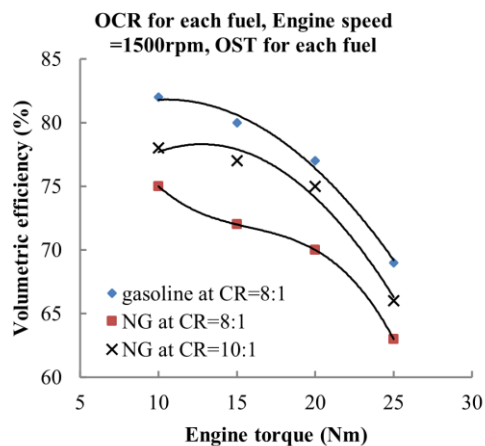


Fig. 14, Comparison of volumetric efficiency for gasoline and NG at variable torques

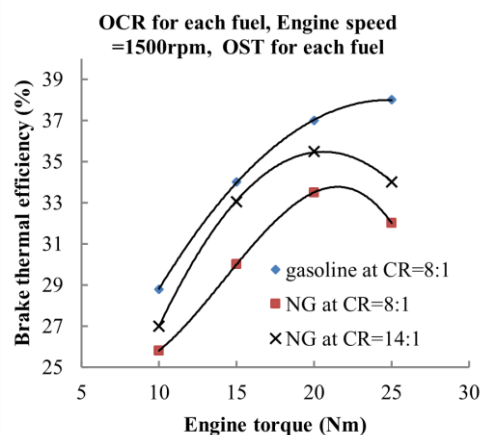


Fig. 15, Comparison of brake thermal efficiency for gasoline and NG at variable torques

Fig 16 represents the effect of engine torque on exhaust gas temperatures for the studied cases. Gasoline still emitting the higher temperatures compared with NG. NG at its HUCR emitted exhaust gas temperatures close to that emitted by gasoline. While NG at CR=8:1 still emitting lower exhaust gas

temperatures due to its lower heating values and its mixtures with air lower burning velocities.

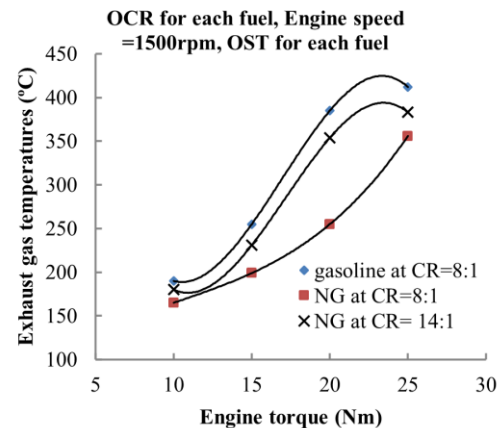


Fig. 16, Comparison of exhaust gases temperatures for gasoline and NG at variable loads

C. Comparison with other researches

The comparison of recent study with other published papers to validate the study results is manifested in fig. 17. The comparison was made on the variation of bsfc related to engine speed variation. It can be seen from the curves that the results are converging in spite of the differences in NG constituents and the engine used in each study. Ref. [11] utilized single chamber diesel motor changed over to SI motor by altering existing barrel head, Piston get together, Flywheel and supplanting fuel infusion framework with electronic start framework on motor. He used CR=18:1.

Ref. [14] has modified 1.6 liters electronic fuel injection (EFI) gasoline engine by adding three components to CNG system which are: the mixer, swirl device and fuel cooler device. The three components were installed to produce pressurized turbulent flow with higher fuel volume in the intake system, which is ideal condition for compressed natural gas (CNG) fuelled engine.

Geok [10] used a 1.5 liters, single overhead camshaft multipoint fuel injection gasoline engine type (Mitsubishi 4G15) after converting it to a be fueled with CNG by a port fuel injection system and programmable electronic control unit (ECU) were installed to control the CNG operation.

IV. CONCLUSIONS

This article speaks to an examination of motor execution when it was powered with Iraqi routine gas and Iraqi delivered NG. NG engine performance was studied for two cases: at engine CR=8:1 (the higher useful compression ratio of gasoline) and at CR= 14:1 (the NG's HUCR). The results show that HUCR for gasoline was 8:1, and it was 14.0:1 for NG. Gasoline bp is the highest brake powers among the tested cases at HUCR=8:1. Bsfc reduced by using NG at its HUCR, while at CR=8:1 it became higher. Gasoline has the lowest bsfc. Volumetric efficiency reduced by using NG due to its gaseous

nature, but it was improved when the engine was run at HUCR. Brake thermal efficiency for NG was lower than that for gasoline at all speeds and torques. Exhaust gas temperatures reduced by using NG, due to its low burning velocity and its low heating value. Using NG to fuel an automotive engine demands increasing engine compression ratio to achieve the used NG HUCR.

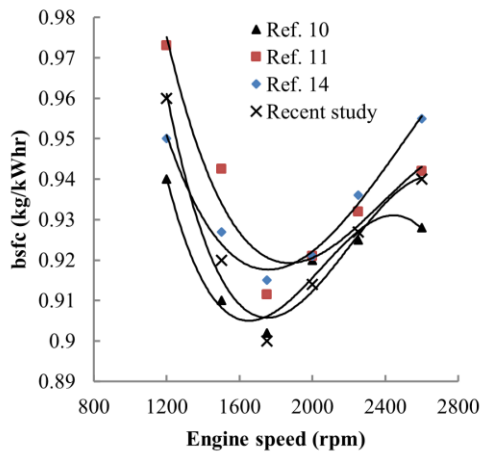


Fig. 17, Comparison of some published studies with recent investigation

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NOMENCLATURE

bp	brake power
bsfc	brake specific fuel consumption
BTDC	before top dead center
bte	brake thermal efficiency
CR	compression ratio
HUCR	higher useful compression ratio
OST	optimum spark timing
$\dot{m}_{theo.}$	Theoretical air flow rate
$\dot{m}_{a,act}$	Actual air flow rate
NG	natural gas
SIE	spark ignition engine
$V_{s,n}$	Displacement volume
η_{vol}	volumetric efficiency
η_{bth}	brake thermal efficiency
ϕ	equivalence ratio